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NOVAE AND VARIABLE STARS*

By Harlow Shapley

In the following pages I shall try to show that the differences between novae and certain classes of variable stars are less conspicuous than is commonly believed, and it may follow as a corollary that the causes of the light variations of novae and of these particular variables differ in degree rather than in character. It will appear that photometrically the novae differ among themselves more than some of them differ from irregular variables, and that a few objects are clearly intermediate between these two classes of stars.

If a nova, or so-called new star, were actually a new star, the investigation of the origin of celestial bodies might be turned mainly to these sporadic objects; but novae may be and probably are old stars; their spectacular phenomena are possibly the signs not of stellar origin, but of stellar death or transformation. They do, however, indicate variation on an enormous scale; and since in astronomy, as in all branches of science, variation is the key to evolution, the study of novae will undoubtedly throw light on important phases in the development of stars.

Unfortunately we know very little as to causes of stellar variation. All kinds of variables, from the nova to the eclipsing binary, from the cluster type variable to the Sun, have unsolved problems connected with them. Stellar variability is, in fact, almost completely unsolved, notwithstanding the extensive accumulations of photometric, spectroscopic, and statistical data. The eclipse theory, of course, takes care satisfactorily of one kind of variation. That kind, however, merely involves occultations and rotations of luminous surfaces, and not intrinsic variation of the light originating on the surfaces. The small intrinsic variations occasionally found in eclipsing binaries are not satisfactorily accounted for.

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*Adapted from a lecture given in Native Sons' Hall, San Francisco on the evening of February 25, 1921 under the auspices of the Astronomical Society of the Pacific.

There are, to be sure, various incomplete hypotheses to account for the other types of variation; for example, the nebular friction and explosion theories of novae, the veil theory of long period variables, the planetary disturbance theory of the Sun's variation, the pulsation theory of Cepheid and cluster-type variables, the periastron and resisting medium theory of the secondary effects for eclipsing binaries. But none of these hypotheses is universally accepted, and none should be. Some of them, agreeing rather fully and well with present knowledge, must be regarded, however, as successful theories in that they are useful theories; they serve in directing future work, in correlating superficial phenomena otherwise unorganized, and in throwing light on collateral researches. More than this could scarcely be expected of working hypotheses.

Before discussing the similarities between novae and variable stars, it may be noted that there are two properties of stellar variation that are common to nearly all classes and sub-classes of variables.

First is the property that the increase in light is more rapid than the following decline. The novae frequently rise to maximum luminosity in a day or two and require a year or more to return to the original faintness; some cluster type variables attain in two hours a brightness that requires ten hours for fading out. Most long period variables, practically all Cepheids, and even the irregular variables and the Sun conform to this general tendency. In fact, the lack of symmetry that appears so persistently in the most accurate light curves of eclipsing binaries is in the same sense—a rise from minimum light quicker than the decline. This last case may be quite unrelated in cause to the others; but for novae and for irregular, long period, and Cepheid variables the underlying similar asymmetry in the light curves must be reckoned as one of the basic phenomena of stellar variation.

The second common characteristic of all classes of variable stars is the concurrent change in spectral type and magnitude. This condition, long ago recognized for novae and long period variables, is now listed as a fundamental property of short period variation.

In the case of eclipsing binaries, the spectral change is mainly indicative of dissimilar components; but for the other classes the change in spectrum is both an indication and a consequence of intrinsic change in light emission. The variation in luminosity is actual, not merely apparent. The hypothesis that the operating

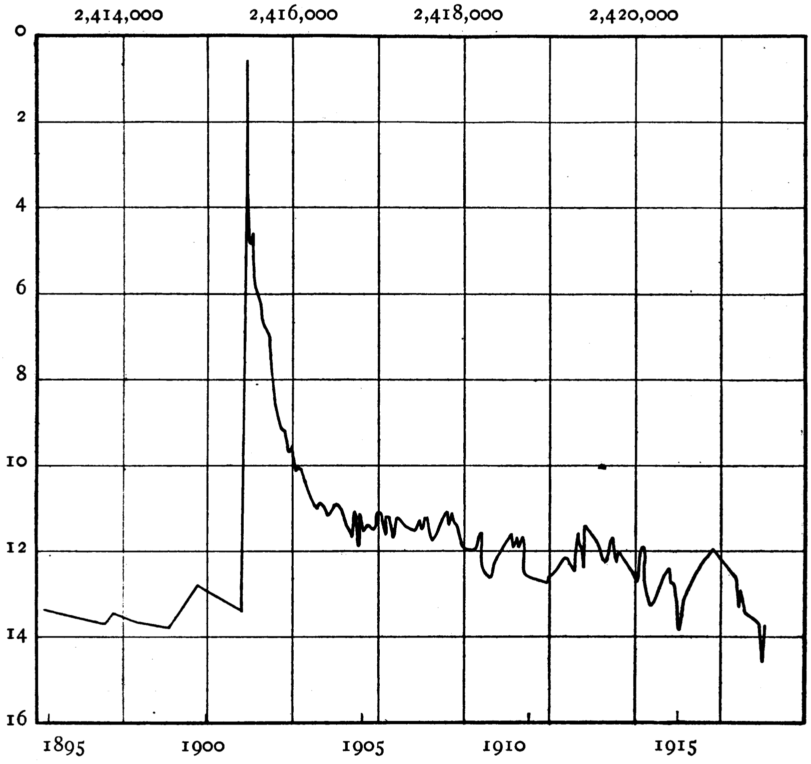


FIG. 1. Photographic light curve of Nova Persei No. 2

In this and all the following figures, except Fig. 2, the ordinates are photographic magnitudes and the abscissae are years and Julian Days (above). All light curves, except those of Fig. 2 are based entirely on observations made at the Harvard Observatory

cause of Cepheid or long period variation lies outside the stars fails because of the ever-growing evidence of continuous spectral change.

The rapid and striking changes in the spectra of the brighter novae have long isolated them from ordinary variable stars, but many connecting links are now being found, as the following discussion shows.

A series of figures illustrating the various forms of light curves, will readily bring out transition types between novae and irregular variables. The nova that is commonly called typical rises very suddenly from obscurity, attains maximum brightness within two or three days, and immediately begins to decline, at first rapidly, then more slowly, until a faint magnitude is reached, or the object gets wholly out of telescopic range.

Nova Persei No. 2 is considered a typical case; but, as is shown in Figure 1, which is based on Harvard photographic magnitudes, the star apparently existed for at least six years before the outburst in 1901. The same is true of several other novae recently discovered photographically. *Nova Aquilae* No. 3 has a record as a star slightly variable for thirty years antecedent to its career as a nova. It is probable that if our telescopic power were not limited, all novae might have been found to exist as stars in pre-nova times, and that all still exist.

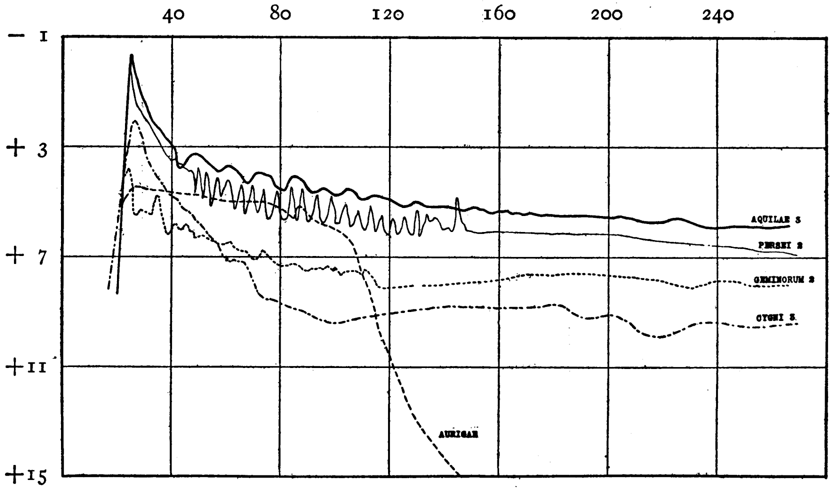


FIG. 2. Visual light curves of five bright novae near maximum light

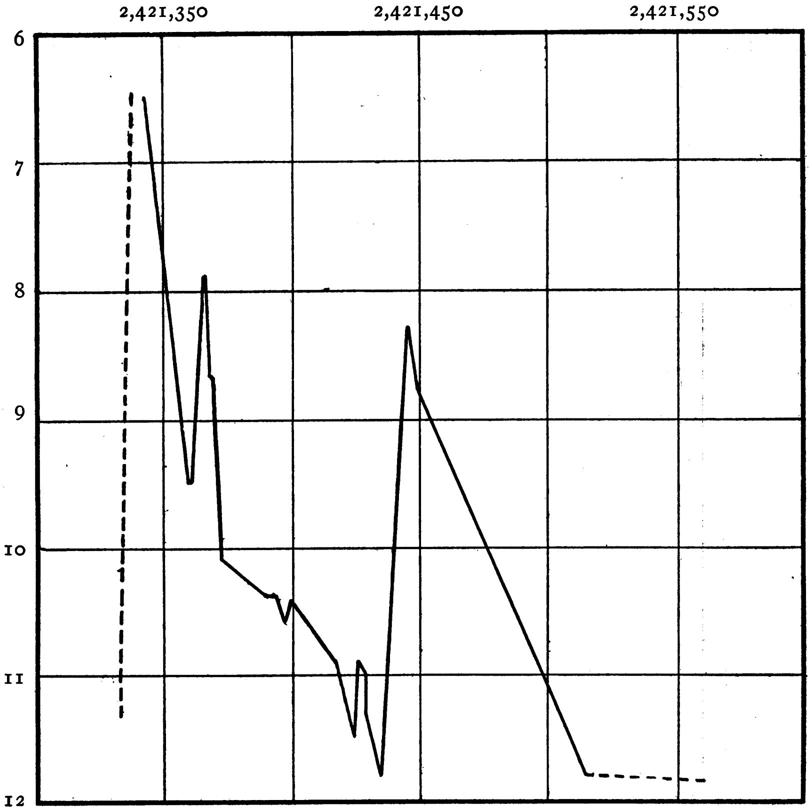
Ordinates are visual magnitudes; abscissae are days.

The light curves of five bright novae are given in Figure 2 to illustrate the nature of the variation near maximum light. The curves are based upon visual observations collected and discussed by Mr. Campbell of the Harvard Observatory. The time scale differs from that of Figure 1, and thus gives another aspect of the variation of *Nova Persei* No. 2.

Figure 2 well illustrates the oscillations that frequently persist for two or three months during decreasing light. It also shows conspicuously, in the long maximum and sharp decrease in light for *Nova Aurigae*, that novae differ much among themselves photometrically.

A flat maximum similar to that of *Nova Aurigae* appears to have been a characteristic of *Nova Persei* No. 1 and of *Nova Aquilae*

No. 4. The former is known only from Harvard photographs; for forty-six days in 1887 its magnitude was about 9.5 and it appears on no plate before or after that date.[1] The latter appears to have remained near maximum magnitude for more than a year.[2]



April, 1917

FIG. 3. Photographic light curve of Nova Ophiuchi No. 5

The irregularities after maximum are not always represented by quasi-periodic waves in the light curve. In the case of *Nova Ophiuchi* No. 5, illustrated in Figure 3, two very distinct secondary maxima occur.

Nova Ophiuchi No. 4 departs still farther from the suddenly-appearing single maximum type of novae. The Harvard photographic light curve in Figure 4 shows a remarkable double maximum (magnitude 7.4), and the two high peaks of the curve, twenty-five days apart, are separated by a minimum nearly two magnitudes deep. Of still more significance, the curve for this nova also shows that the star had risen from obscurity to the ninth magnitude three weeks before it suddenly increased to its first maximum. Such a light curve suggests a continued series of impulses; the data are certainly not out of harmony with the Seeliger-Monck hypothesis that the novae are consequences of the passing of a star thru nebulous fields.

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[1] For this and other notes I am indebted to the study of photographic light curves of novae, to be published in *Harvard Annals* **84**, under the direction of Miss Leavitt.

[2] *Harv. Bull.* 753, 1921.

I have previously called attention to the possibility that the temporary stars in spiral nebulae, which show the characteristics of novae in the fragmentary records of their light variations, are generated in an analogous manner, that is, by the encounter of star and nebula. The high velocity of spirals lends some support to the suggestion; the frequency of novae in the *Andromeda Nebula* may be against it.

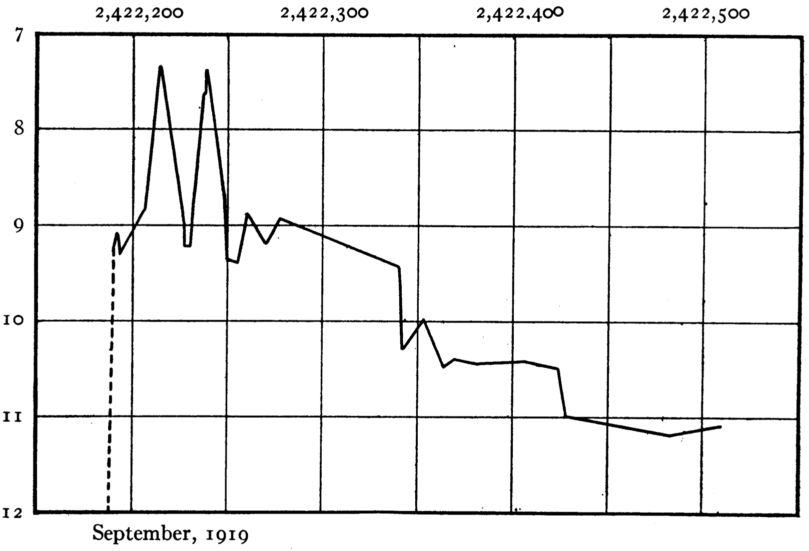

FIG. 4. Photographic light curve of Nova Ophiuchi No. 4

In view of the last two novae cited, there should be no hesitancy in placing Miss Leavitt's peculiar variable, T *Pyxidis*, with the novae.[3] The observations on its spectrum by Miss Cannon made such assignment necessary.[4] Thanks to the Harvard photographs, three of the maxima of T *Pyxidis* have been recorded (Figure 5), separated by intervals of twelve and eighteen years.

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[3] *Harv. Circ. 179*, 1913. [4] *Harv. Bull. 716* and *717*, 1920.

Nova Sagittarii No. 5, found by Miss Woods on Harvard photographs, is another case of a recurrent nova.[5] Until it rose to the seventh magnitude in April, 1919, it was normally of magnitude 14, except that eighteen years previously, in 1901, there occurred a temporary increase of three magnitudes.

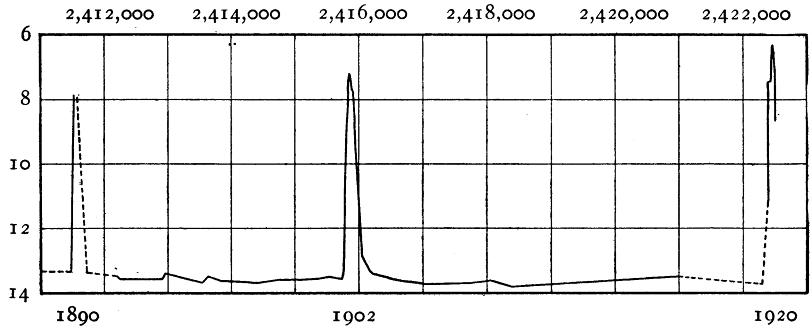

FIG. 5. Photographic light curve of T Pydixis

At minimum the light has uncommonly little variation for stars of this type

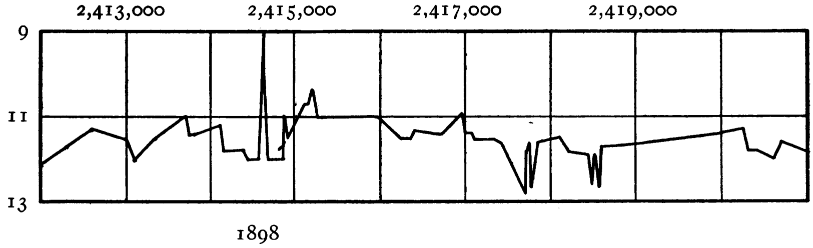

FIG. 6. Photographic light curve of RS Ophiuchi

Figure 6 shows the light curve of RS *Ophiuchi*, a star that would certainly be classed as an irregular variable if it were not for its nova-like spectrum and the one sharp maximum in 1898. Similarly, if we did not have its early history, *Nova Persei* No. 2, a most typical nova, might be mistaken for an irregular variable on the basis of the light curve of the last ten years (Figure 1.)

RS *Ophiuchi* lies in the rift in the Milky Way and, like many other temporary stars, appears to be in the vicinity of diffuse nebulosity. The irregularities in the light variations of such objects are probably no more pronounced than the irregularities in the nebulous clouds thru which they may be moving.

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[5] *Harv. Circ. 693,* 1919.

The stars RX *Puppis* and Z *Andromedae* (Figure 7), which have spectral characteristics similar to the novae, are other steps in the photometric sequence from *Nova Persei* No. 2 to the ordinary irregular variable. If the maxima of either are regularly recurrent, the period must be of the order of at least twenty years; but it is more likely that the light of both changes irregularly and for the same reason that the light of any nova changes.

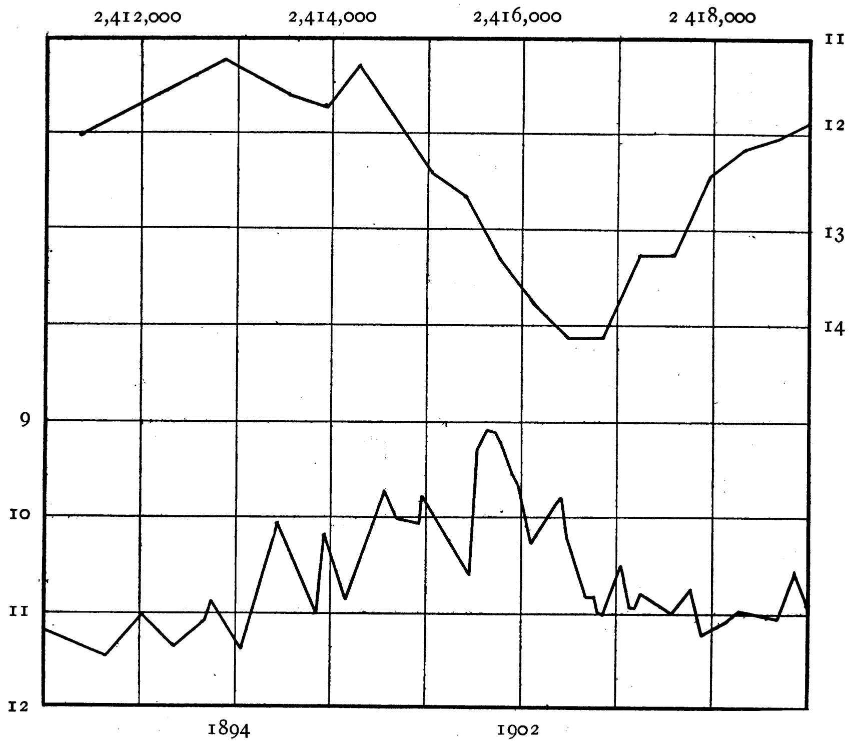

FIG. 7. Photographic light curves of RX Puppis above, and Z Andromedae below

The light curves and remarks given above are sufficient, I believe, to maintain the view that novae and certain kinds of irregular variable stars are closely allied. It is of course not in the least probable that all irregular variables are affiliated with novae, particularly such red irregular variables as *α Herculis* and *α Orionis*.

But it is probable that many old novae, and the miniature novae of the RS *Ophiuchi* type, do exist at the present time as irregular variable stars.

It should be remembered that galactic novae bright enough to get into our records have been occurring at the rate of about one a year for the last thirty years. This fact has been made certain by the systematic search of Harvard photographs inaugurated by Professor Bailey. Presumably this rate has been approximately maintained in the past for indefinite ages. Is it not likely that thousands of objects existing now were once novae?

On the basis of the spectroscopic evidence, one of the end products of novae appears to be akin to planetary nebulae; the distribution in the sky supports that view. The known planetaries may indeed be the outcome of special or of very great explosive phenomena, but they are not numerous enough to represent all novae. The stars of the P *Cygni* type and the variable T *Coronae* show, however, that there may be other end products of the phenomena called novae. The spectrum of T *Coronae*, fifty years after it was a nova, is classified[6] by Miss Cannon as KO; its light variations at present are small. The peculiar spectrum of P *Cygni* (*Nova Cygni* No. 1), three centuries after its first recorded appearance, has some of the characteristics of the spectra of novae; its light has been constant for almost 250 years.

If the great velocity of 300 km./sec. with which the *Andromeda Nebula* moves with respect to the Sun, can produce, as suggested above, a nova of great magnitude range, what would be the result if nebulosity of an appropriate kind should move with a small velocity with respect to the stars it encounters? Would miniature novae occur?

The relative velocity of the various parts of the *Orion Nebula* is a few kilometers a second. Are the one hundred variable stars in the nebula related to novae in cause and effect? I have discussed this possibility elsewhere[7], and will only remark here that no periodicity has yet been announced for the variables in the *Orion Nebula*, altho extensive studies of them have been carried on at the Yerkes, Flagstaff, Mount Wilson, Harvard and Hamburg Observatories, and probably elsewhere. The stars apparently are dwarfs and therefore unlike any other class of variable[8]; their light variations appear to be quite irregular, they are mostly of small range, and at least one of them has been called "nova-like" by the discoverer.

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[6] *Harv. An.* **76**, 37, 1916.

[7] Note on a Possible Factor in Geologic Climates, *Journal of Geology*, (in press.)

[8] *Mt. Wilson Contrib.*, No. 156, p. 12, 1918.

In conclusion it is interesting to notice that at least two objects appear to be entitled to the name new star in a literal sense. They are stars which have increased in brightness from the unknown, and do not fade away. One of these stars, RT *Serpentis*, I discussed in an earlier volume of these PUBLICATIONS[9]; it has been of magnitude 11 for the last seven years, first appearing in 1909 as a star of magnitude 14. The other is 27. 1920, which, according to Wolf[10], appeared in 1908 and had reached the eleventh magnitude in 1920. Eventually these two stars may fade away; or they may be stars slowly emerging from behind obscuring clouds, rather than objects newly born. But their history as now known entitles them to the name new star without quotation marks or qualifications.

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[9] *Publ. A. S. P.*, **31**, 226, 1919. Cf. also *Harv. Bull.* 753, May, 1921.
[10] *A. N.* **212**, 75, 1920.

THE VARIATION OF LONGITUDE*

BY R. H. TUCKER.

The variation of astronomical longitudes is more difficult to detect than the corresponding and simultaneous variation of latitudes. The only obvious direct test is that of the variation in the readings of the level of a meridian circle. The results of the zenith telescope observations for latitude may be considered to be practically the observation of the changes in the delicate level attached to the instrument. These changes are due to the variation in the inclination, north and south, of the line representing the direction of the gravitational attraction of the Earth. Observations of latitude with a meridian circle record the same variations of the vertical.

Level observations in meridian circle work measure primarily the variations in level of the supports of the instrument. They include also the effects of any variation, east and west, of the line representing the direction of gravity. If an instrument could be constructed, the supports of which would have no variations in level, the test

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*Presented at the Berkeley meeting of the Society, August 4-6, 1921.